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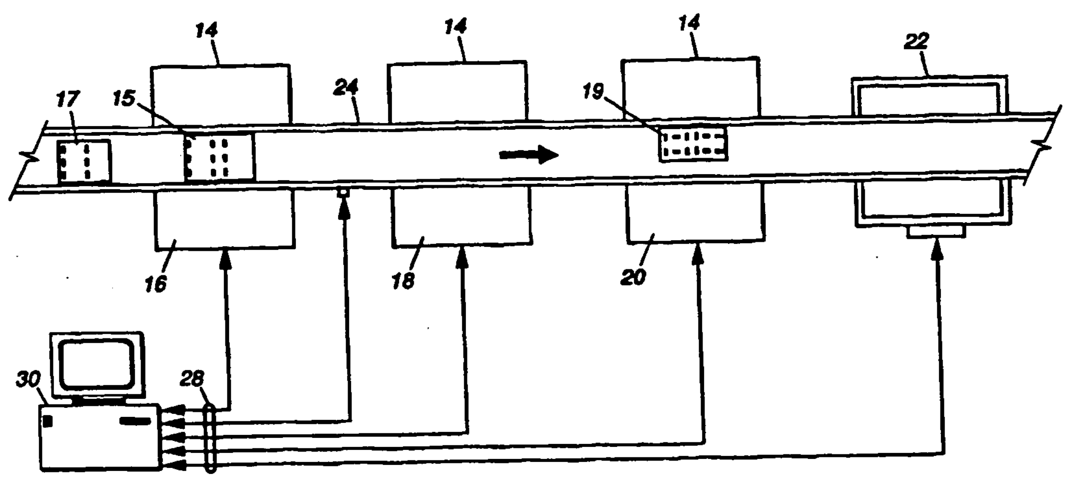

(57) Abstract

A method of reconfiguring a production line for fabricating printed circuit board assemblies to achieve maximum efficiency and maximum flexibility is disclosed. The production line has one or more placement stations (16, 18, 20), a reflow oven (22), a conveyor (24) and a controller (30). The controller communicates with the various components (placement stations, reflow oven, conveyor) of the production line to transfer information related to the state of assembly of some of the printed circuit board assemblies (15, 17, 19) that are being processed. The controller also communicates information related to the status of the various other stations. The operational functionality of one or more of the placement stations, the reflow oven, or the conveyor is altered in response to the communication by the controller. Other remaining modules continue operation unaltered during this step of dynamic reconfiguration.

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DYNAMICALLY RECONFIGURABLE ASSEMBLY LINE FOR ELECTRONIC PRODUCTS

FIELD OF THE INVENTION

This invention relates to an assembly line for manufacturing electronic assemblies such as printed circuit boards containing discrete components. The invention is particularly useful for, but not necessarily limited to, maximizing the utilization of the assembly line while at the same time providing maximum flexibility in product mix and volume.

BACKGROUND

In production assembly lines used for mounting electronic components to circuit boards, the circuit boards are generally conveyed through the assembly line on conveyors. Various assembly processes such as solder stenciling, component mounting and reflow soldering are typically performed. Typically, the conveyors are parallel tracks that carry the circuit board through the various stages of assembly, from one station to another. During conveying it is common practice to support the circuit boards along the edges and maintain them in a substantially horizontal plane and isolated from vibration so that the possibility of component misalignment is reduced.

In conventional systems, the assembly line is usually optimized to enable high efficiency and throughput. This is because of the substantial capital cost of the highly sophisticated and automated equipment employed in modern circuit board assembly lines. A typical line costs two million dollars, and some are as high as ten million dollars. Obviously, one is desirous of operating at highest efficiency in order to realize maximum return on the dollars invested in the equipment, and assembly lines are typically dedicated to a single product so that down time required to reconfigure the assembly line is minimized.

On the other hand, the demands of the modern marketplace are such that it is desirous to produce a variety of products in order to satisfy the increasing appetite for electronics that provide features that are tailored to the individual consumer. This means that either several dedicated lines must be employed, or the line must be frequently reconfigured. In the first case, the capital cost for additional lines is high, and additional engineering overhead must be provided in order to keep these sophisticated lines running smoothly. In the second instance, reconfiguring the line requires that the line be stopped and reconfigured. Even with today's formidable computing power, downloading new programs consumes precious time and decreases the utilization of the assembly line. Utilization is the converse of flexibility, and thus, the manufacturer is forced to choose from two mutually exclusive goals, high flexibility or high utilization. The industry has struggled in vain for many years in attempts to find a solution to this dilemma. To date, all prior art solutions have been a compromise, sacrificing one goal in pursuit of the other. The ability to have maximum utilization and maximum flexibility on the same assembly line would be a valuable addition to the art.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGs. 1 and 2 are schematic views illustrating a dynamically reconfigurable production line in accordance with a preferred embodiment of the invention; and

FIG. 3 is a schematic view illustrating a placement workcell for a dynamically reconfigurable production line in accordance with an alternate embodiment of the invention.

SUMMARY OF THE INVENTION

A method of reconfiguring a production line for fabricating printed circuit board assemblies to achieve maximum efficiency and maximum flexibility is disclosed.

The production line has one or more placement stations, a reflow oven, a conveyor and a controller. The controller communicates with the various components (placement stations, a reflow oven, a conveyor) of the production line to transfer information related to the state of assembly of some of the printed circuit board assemblies that are being processed. The controller also communicates information related to the status of the various other stations. The operational functionality of one or more of the placement stations, the reflow oven, or the conveyor is altered in response to the communication by the controller. The other remaining modules continue operation unaltered during this step of dynamic reconfiguration.

While a first activity is being performed on a first electronic assembly in the first placement workcell, a controller monitors other placement workcells that are downstream. If a downstream workcell is idle, then it sends a signal to the controller that indicates such, and the first placement workcell is dynamically reconfigured. This can occur while the first workcell is in operation, in response to a signal from the controller. After reconfiguration, the conveyor transports the first electronic assembly from the first placement workcell to the second placement workcell. A second electronic assembly is then conveyed into the first placement workcell, and a second activity is performed on the first electronic assembly in the second placement workcell. The required activity is also performed on the second electronic assembly in the dynamically reconfigured first placement workcell.

The controller is responsive to information related to the degree of completion of the activity that is being performed on the various electronic assemblies. In some instances, the operation of the remaining modules continues unaltered during the step of dynamically reconfiguring.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

While the specification concludes with claims defining the features of the invention that are regarded as novel, it is believed that the invention will be better understood from a consideration of the following description in conjunction with the drawing figures, in which like reference numerals are carried forward. When an electronic product is being assembled, it typically flows down an assembly line or production line. To best understand our invention, the following description assumes that the production line has been running for some period of time and that it contains a number of electronic products or assemblies in various stages of completion at the various stations. The electronic product typically begins as a printed circuit board (PCB), upon which various components such as resistors, transistors, microprocessors, capacitors, etc. are placed. The components are placed onto the board by robots or other highly automated machines, such as chip shooters. It should be understood and appreciated that our invention is directed to the use of robots or other machinery as opposed to manual systems where components are placed onto the board by human hands. These various components are then typically attached by reflow soldering them onto the printed circuit board. The production line consists of one or more (typically several) placement machines such as robots. The placement machines are variously referred to as pick-and-place machines, workcells, robots, workstations, placement modules, chip-shooters, etc. in the industry parlance. Each workcell or station typically has a predetermined set of components that can be placed on the PCB. These components are loaded into feeders contained in the workcell, and the robot or placement means selects from the various feeders to place the desired set of components on the PCB. A software program resident in the workcell directs the robot as to which components to select and where to place them on the PCB. The placement of components in each workcell requires a finite period of

time, and when the cycle in each workcell is complete, the PCB is then conveyed into the next workcell.

Although the aforedescribed system of placing components is typical in the electronics industry, our invention deviates from the prior art in the following way. Referring now to FIG. 1, a first PCB 15 enters the first workcell 16 and the workcell begins placing components or parts onto the PCB. Another PCB 17 is queued up waiting for the first workcell 16 to finish its cycle. If, during the course of the cycle of placing the various components, another workcell 18, 20 that is downstream (i.e. farther down the production line) is idle or is nearing the end of its cycle, the first workcell is dynamically reconfigured (i.e. the program is altered while it is running). The cycle of placing components in the first workcell 16 is interrupted and abbreviated so that the PCB 15 can now move into the next, or second, workcell 18, which was idle. After the first PCB 15 exits the first workcell 16, another, or second, PCB 17 enters the first workcell to have various components placed thereon. Depending on the state of the production line, the first workcell can either be reconfigured prior to the second PCB 17 entering, or it can remain in the same configuration state as it was when the first PCB 15 left. Referring now to FIG. 2, the second workcell 18 now places the components that were originally destined to be placed on the first PCB 15 prior to the first workcell being dynamically reconfigured. The second workcell 18 typically has a set of components that it normally places on the PCB, and depending on the available time and state of the workcells further downstream, these may or may not be completely placed. The feeders in the second workcell 18 contains a subset of the components found in the first workcell. The principle, heretofore unrealized, is that each workcell is capable of placing some or all of the parts of the workcell that is upstream of itself, and both workcells are capable of being dynamically reconfigured. Thus, the amount of time that any single

workcell in the production line is idle is minimized and the efficiency of the line is maximized. To rephrase, when a bottleneck occurs at a certain station, it can be immediately alleviated by shifting some of the workload to one or more downstream stations that have idle capacity. In addition, or alternatively, some of the workload can be shifted to one or more upstream stations that have idle capacity.

One skilled in the art should now appreciate that the prior art solutions to this problem attempted to optimize the software program at each workcell to balance the line, based on some theoretical model or historical data. The program was then 'frozen' into each station. However, even the most sophisticated modeling system can only predict the future based on past performance, and once the program is 'frozen' into the workcell memory, the line instantly becomes sub-optimized whenever a deviation from the model occurs, as it always does. By dynamically reconfiguring the production line based on the actual current states of the various components in the system, we can now balance the production line so that it continually operates at maximum efficiency. And clearly, having the ability to dynamically reconfigure the line also provides the maximum flexibility, because each workcell can be instantly altered to reflect a change in the product mix.

In practice, information and signals are passed back and forth between the various workcells or modules and a master controller 30. The controller is typically a high speed computer that serves to allocate resources amongst the various workcells in order to optimize the efficiency of the production line. Depending on the actual implementation of the system, the controller 30 may simply pass a signal to the first and second workcells 16, 18 and these workcells then alter the software within their respective systems. Or, the controller can actively modify the software program for each workcell and pass it to the respective workcell for implementation. In either case, some type of information on

the state of the cycle in each workcell is being passed from the workcells to the controller 30, and other information (e.g. instructions for dynamically reconfiguring) is passed back to these same workcells. As a result of this information flow, the operational functionality of one of the workcells can be dynamically reconfigured while the others continue to operate unaltered.

Although we have, to this point, disclosed modifying the operational functionality of robot workcells or pick-and-place machines, the principles of our invention can also be applied to other segments of the assembly line, for example, to the conveyor 24, the reflow oven 22 or the solder printer. The screen printer and the reflow oven can be dynamically reconfigured to adjust to the dynamic needs of the product mix. The reflow is typically an oven, but can also be a robot with a heating chamber, thus lending itself to quick reconfiguration. In another example, there may be one or more solder printers that are automatically capable of printing a multiplicity of different patterns on different PCBs, arranged serially or in parallel. Depending on the state of the various printers, each of these printers can be dynamically modified to optimize the throughput of the line. Likewise, by using a conveyor or transport means that is capable of changing speed or accommodating PCBs of various sizes, one can radically reconfigure the production line so that various sizes of PCBs and thus various types of electronic assemblies are produced on the same line at the same time, and in response to changing conditions of utilization of the various workcells in the line. When conventional conveyors are used to convey circuit boards of different widths, a circuit board of one width is conveyed out of the parallel tracks after which the distance between the tracks is adjusted to accommodate a circuit board of a different width. Another method of conveying is disclosed in U.S. Patent No. 4,759,436 where a conveyor with a plurality of aligned rollers forms a track and corresponding adjustable supports for conveying objects along a curved

path. The supports are pivotal about a horizontal axis to accommodate movement of a respective free end that supports one of the objects. This conveyor does not have parallel tracks that need adjustment and can be used to convey circuit boards of different widths. Likewise, U.S. Patent No. 4,840,268 discloses an adjustable width chain conveyor. The conveyor has two parallel and inclined channels within which are mounted a respective continuous chain coupled to a drive. Each chain can slide inwardly or outwardly to accommodate for small variations in widths of circuit boards being conveyed. Still another means of conveying various sized PCBs is to utilize dual, parallel conveyors on the production line. Two conveyors are run side by side through each of the workstations. This not only allows various sized PCBs to be processed, but can add to the flexibility of the production line by allowing the various workcells to perform different functions on different electronic assemblies. Advantageously, the conveyor can convey circuit boards of different widths without the need for completely conveying one board through the conveyor before boards of a different width can conveyed.

In summary, the above preferred embodiment of our novel invention provides a method to process a sequence of electronic assemblies, where the activity being performed on each assembly is different, and where the various workcells can be dynamically reconfigured.

Referring now to FIG. 3, a schematic view of a placement workcell 32 in accordance with an alternate embodiment of the invention is illustrated. Placement workcell 32 comprises placement executor 33, a conveyor 34 and a controller 35. Placement executor 33 includes a component feeder 36 and a component placer 37. Controller 35 couples to control placement executor 33 and conveyor 34. Conveyor 34 is associated with placement executor 33 and conveys PCBs (not shown) from a preceding placement workcell (not shown) to placement workcell 32 or from placement workcell 32 to a placement workcell (not shown). The

preceding or subsequent placement workcell need not be next in sequence with placement workcell 32. For example, there may be one or more intermediate placement workcells between the preceding placement workcell and placement workcell 32.

Controller 35 determines one or more operations for executing by placement executor 33. In this alternate embodiment, the operations are placement operations in which component placer 37 places components from component feeder 36 onto PCBs. Information associated with the PCBs may be provided to controller 35 by the preceding placement workcell to determine the operations. Controller 35 can reduce these operations by controlling placement executor 33 in response to an idle status signal from the subsequent placement workcell. The idle status signal indicates to controller 35 that the subsequent placement workcell is ready to accept a PCB from placement workcell 32. Controller 35 also provides information on executed or unexecuted operations for the PCB to the subsequent placement workcell.

The invention advantageously executes operations on PCBs with placement workcell 32 depending on how many of the operations have been executed or unexecuted by preceding placement workcells. Furthermore, the operations of placement workcell 32 can also be executed by subsequent placement workcells depending on availability of the subsequent placement workcells to execute the operations. A production line having two or more placement workcell 32 coupling together can attain a dynamic line balance with a minimum use of buffers. Hence, unlike prior art production lines that control buffers or slows down placement workcells for line balancing, placement workcell 32 in the invention continuously execute operations without slowing down or stopping because of performance of other placement workcells.

While the above embodiments of the invention have been illustrated and described, it will be clear that the invention is not so limited. Numerous modifications, changes, variations, substitutions and equivalents will

occur to those skilled in the art without departing from the spirit and scope of the present invention as defined by the appended claims.

We claim:

CLAIMS

1. A method of reconfiguring an assembly line for printed circuit boards to achieve maximum efficiency and maximum utilization, the assembly line having a placement module, a reflow module, a conveyor module to transport the printed circuit board, and a controller, comprising;

performing an operation upon the printed circuit board in one of the modules;

communicating between the controller and one of the modules to transfer information about one of the circuit boards;

reconfiguring operational functionality of any one or more of the placement modules, the reflow module, or the conveyor module in response to the step of communicating while said any one or more module continues the step of performing an operation upon the printed circuit board.

2. The method as described in claim 1, wherein the step of communicating is in response to and is a function of the step of performing an operation upon the printed circuit board.

3. The method as described in claim 1, wherein the step of communicating is in response to and is a function of the operational functionality of one of the modules.

4. A method of reconfiguring a production line system, for fabricating circuit boards, the production line having a placement module, a reflow oven module, a conveyor module, and a controller, the method providing maximum efficiency, comprising;

communicating between the controller and one of the modules to transfer information related to a condition of one of the circuit boards about to be processed by one of said modules or information related to the status of other modules;

reconfiguring operational functionality of any one or more of the placement module, the reflow oven module, or the conveyor module, in response to the step of communicating; and

continuing operation of the remaining modules during the step of reconfiguring while said remaining modules remain unaltered.

5. A method of achieving high utilization and high flexibility on an assembly line for manufacturing electronic assemblies, the assembly line containing a placement workcell, a reflow workcell, a transport means for transporting the electronic assembly from the placement workcell to the reflow workcell, and a controller for the placement workcell, comprising:

performing a primary activity on a first electronic assembly in the placement workcell;

performing a secondary activity on a second electronic assembly in the placement workcell at least partially concurrent with the step of performing a primary activity;

dynamically reconfiguring the workcell in response to the step of performing a secondary activity;

performing a primary activity on the second electronic assembly in the dynamically reconfigured workcell.

6. The method as recited in claim 5, wherein the first and second electronic assemblies are produced in sequence.

7. The method as recited in claim 5, wherein the primary activity performed on the second electronic assembly is different from the primary activity performed on the first electronic assembly.

8. The method as recited in claim 5, wherein the controller is responsive to signals from the primary activity and the secondary activity.

9. The method as recited in claim 5, further comprising another placement workcell coupled to the first placement workcell by the transport means.

10. The method as recited in claim 5, wherein the placement workcell has a primary activity and a secondary activity, the primary activity being dynamically reconfigurable in response to the secondary activity.

11. A method of achieving high utilization and high flexibility on an assembly line for manufacturing electronic assemblies, the assembly line containing first and second placement workcells, a reflow workcell, a transport means for transporting the electronic assembly through the assembly line, and a controller for the workcells and the transport means, comprising the following steps:

performing a first activity on a first electronic assembly in the first placement workcell;

transferring information relating to the state of the second placement workcell from the second placement workcell to the controller;

dynamically reconfiguring the first placement workcell at least partially concurrent with the step of performing a primary activity and in response to a signal from the controller;

transporting the first electronic assembly from the first placement workcell to the second placement workcell via the transport means;

transporting a second electronic assembly into the first placement workcell via the transport means;

performing a second activity on the first electronic assembly in the second placement workcell;

performing a third activity on the second electronic assembly in the dynamically reconfigured first placement workcell.

12. The method as recited in claim 11, wherein the controller is responsive to information related to the degree of completion of the activity that is being performed on the first and second electronic assemblies.

13. The method as recited in claim 11, wherein the steps are performed in the order named.

14. The method as recited in claim 11 wherein the operation of the remaining modules continues unaltered during the step of dynamically reconfiguring.

15. A placement workcell comprising:

a placement executor for executing one or more operations on a PCB;

a conveyor for conveying the PCB, the conveyor being associated with the placement executor; and

a controller coupled to control the placement executor and the conveyor,

wherein the controller is adapted to control the placement executor to reduce the one or more operations in response to an idle status signal and, thereafter, control the conveyor to convey the PCB out of the placement workcell.

16. The placement workcell of claim 15, wherein the controller is adapted to determine information indicative of unexecuted operations of the one or more operations and provide the information to at least one subsequent placement workcell.

17. The placement workcell of claim 15, wherein the controller is adapted to determine information indicative of executed operations of the one or more operations and provide the information to at least one subsequent placement workcell.

18. The placement workcell of claim 15, wherein the controller is adapted to provide an idle status signal to at least one preceding placement workcell when the PCB is conveyed out of the placement workcell.

19. The placement workcell of claim 18, wherein the controller is further adapted to receive information from the preceding placement workcell, the information being for the controller to determine the one or more operations.

20. The placement workcell of claim 15, wherein when the placement workcell is not operating, the controller is adapted to provide an idle status signal to at least one preceding placement workcell.

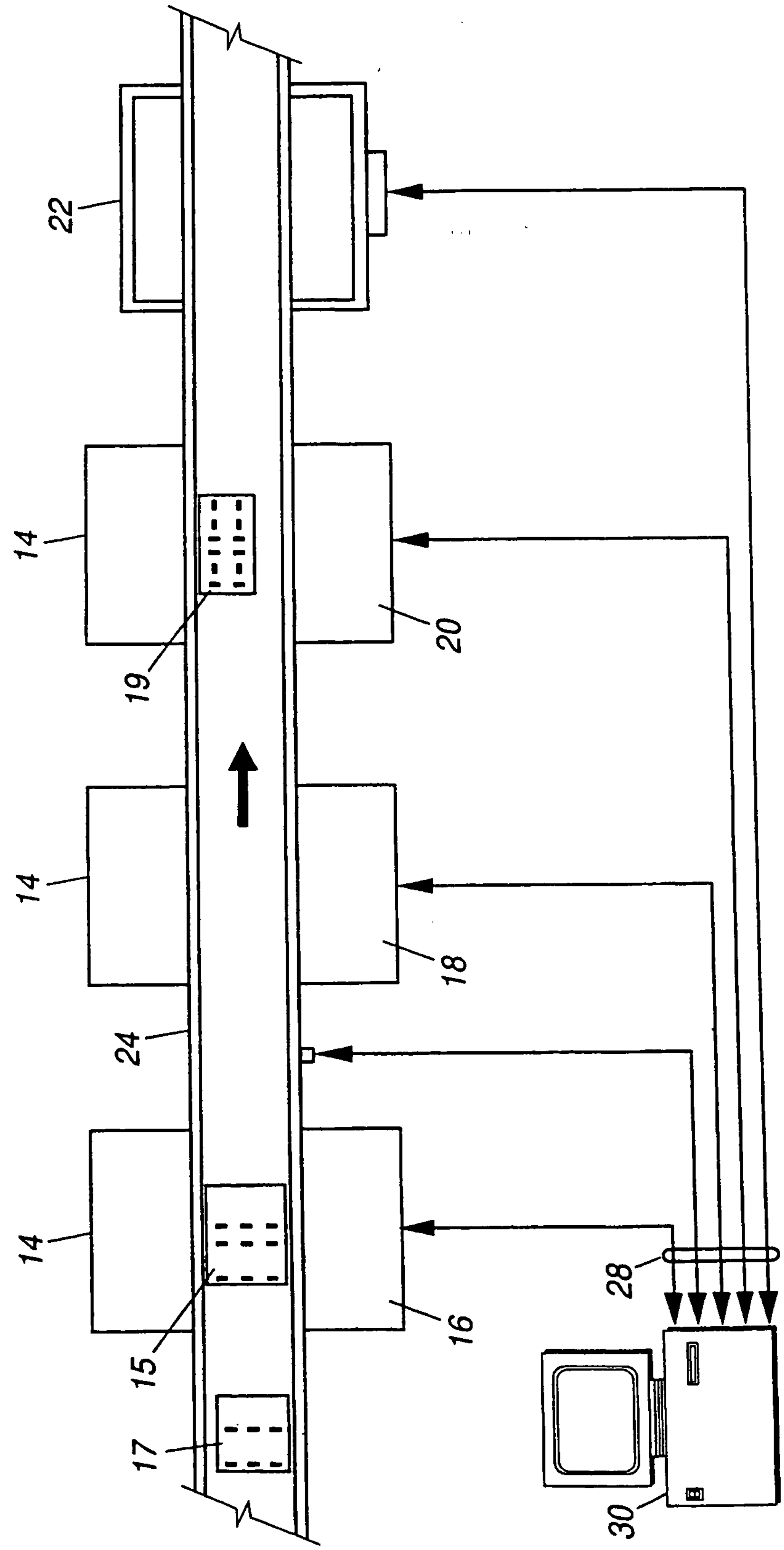

FIG. 1

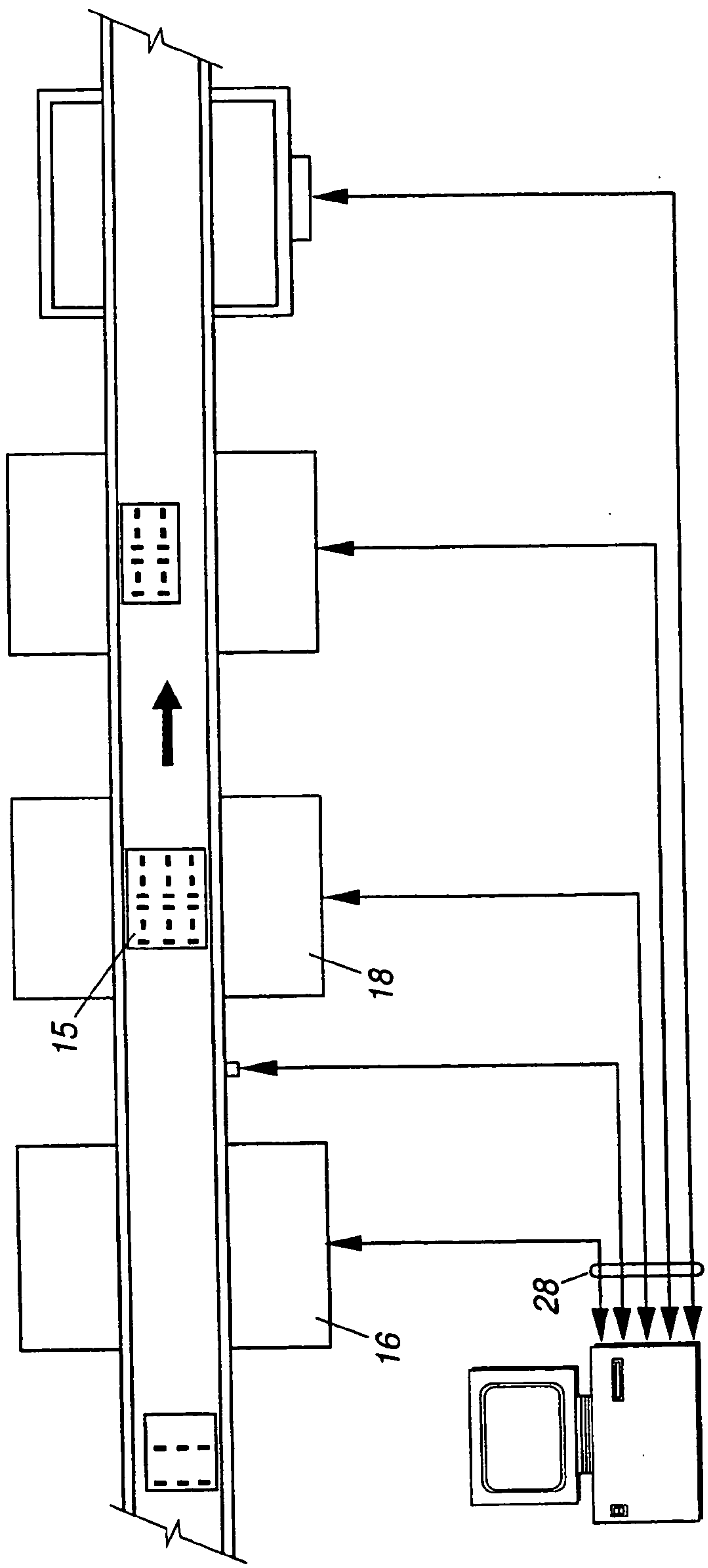

FIG. 2

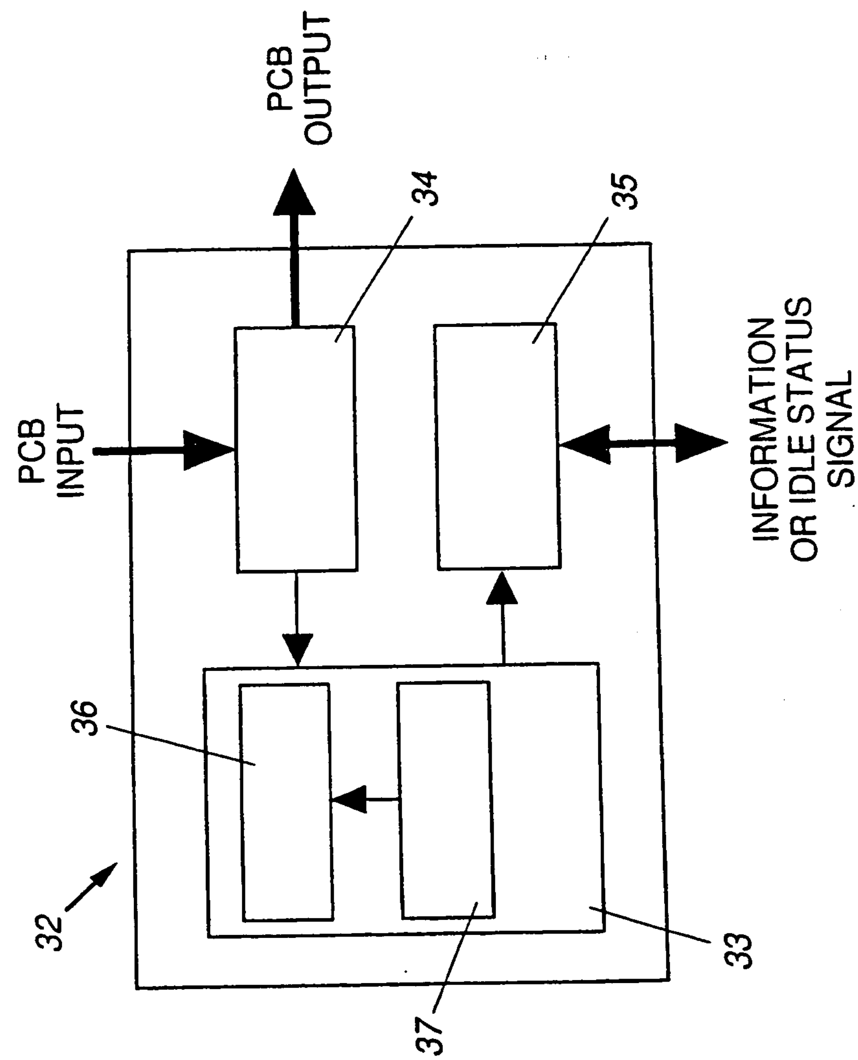
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FIG. 3

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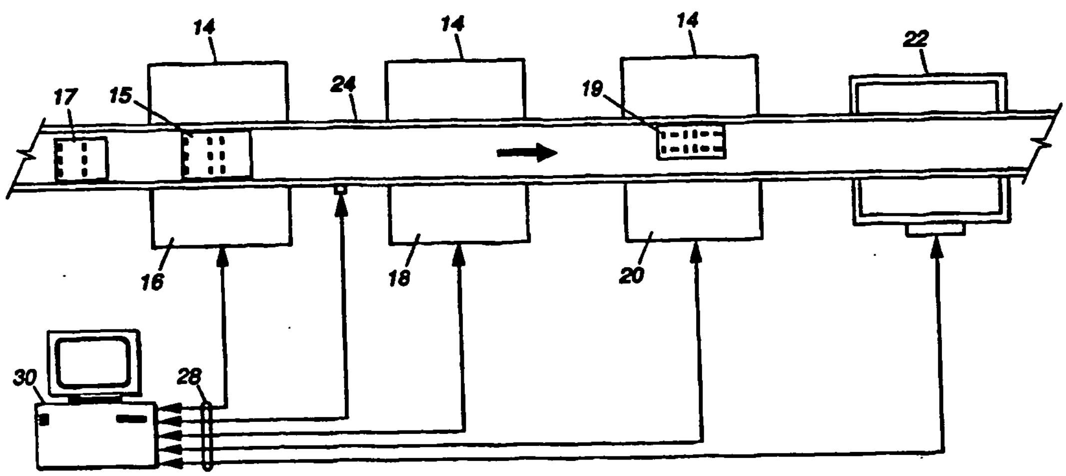

(57) Abstract

A method of reconfiguring a production line for fabricating printed circuit board assemblies to achieve maximum efficiency and maximum flexibility is disclosed. The production line has one or more placement stations (16, 18, 20), a reflow oven (22), a conveyor (24) and a controller (30). The controller communicates with the various components (placement stations, reflow oven, conveyor) of the production line to transfer information related to the state of assembly of some of the printed circuit board assemblies (15, 17, 19) that are being processed. The controller also communicates information related to the status of the various other stations. The operational functionality of one or more of the placement stations, the reflow oven, or the conveyor is altered in response to the communication by the controller. Other remaining modules continue operation unaltered during this step of dynamic reconfiguration.

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GR	Greece
HU	Hungary
IE	Ireland
IL	Israel
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IT	Italy
JP	Japan
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SD	Sudan
SE	Sweden
SG	Singapore
SI	Slovenia
SK	Slovakia
SN	Senegal
SZ	Swaziland
TD	Chad
TG	Togo
TJ	Tajikistan
TM	Turkmenistan
TR	Turkey
TT	Trinidad and Tobago
UA	Ukraine
UG	Uganda
US	United States of America
UZ	Uzbekistan
VN	Viet Nam
YU	Yugoslavia
ZW	Zimbabwe

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US98/08811

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :G06F 19/00
US CL : 364/468.190
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 364/468.190, 167.01; 422/67; 222/64

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5,104,621 A(PFOST et. al.) 14 April 1992, column 17, lines 30-63; column 18, lines 1-11; claims 1-36	1, 3-4, 8-10, 14-20
X	US 5,258,915 A (BILLINGTON et. al.) 02 November 1993, column 8, lines 14-67 - column 9, lines 1-68	2
X	US 5,170,554 A (DAVIS et. al.) 15 December 1992, see entire document	5-7, 12-13

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"B" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
30 SEPTEMBER 1998	02 DEC 1998

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